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PATENT APPLICATION OF

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ENTITLED

METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRICAL SYSTEM

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METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRICAL SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates to the measurement of electrical parameters of a vehicle electrical system. More specifically, the present invention relates to measuring an electrical parameter of an electrical system of a vehicle through the use of multiple measurements.

Electrical systems, such as those which are used in automotive vehicles, consist of a number of discreet components or systems which are interconnected. Techniques for measuring and utilizing parameters, such as dynamic parameters, of electrical systems are shown and disclosed in U.S. Patent No. 3,873,911, issued March 25, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 3,909,708, issued September 30, 1975, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 4,816,768, issued March 28, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE; U.S. Patent No. 4,825,170, issued April 25, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING; U.S. Patent No. 4,881,038, issued November 14, 1989, to Champlin, entitled ELECTRONIC BATTERY TESTING DEVICE WITH AUTOMATIC VOLTAGE SCALING TO DETERMINE DYNAMIC CONDUCTANCE; U.S. Patent No. 4,912,416, issued March 27, 1990, to Champlin, entitled ELECTRONIC BATTERY

TESTING DEVICE WITH STATE-OF-CHARGE COMPENSATION; U.S. Patent No. 5,140,269, issued August 18, 1992, to Champlin, entitled ELECTRONIC TESTER FOR ASSESSING BATTERY/CELL CAPACITY; U.S. Patent No. 5,343,380, issued August 30, 1994, entitled METHOD AND APPARATUS FOR SUPPRESSING TIME VARYING SIGNALS IN BATTERIES UNDERGOING CHARGING OR DISCHARGING; U.S. Patent No. 5,572,136, issued November 5, 1996, entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,574,355, issued November 12, 1996, entitled METHOD AND APPARATUS FOR DETECTION AND CONTROL OF THERMAL RUNAWAY IN A BATTERY UNDER CHARGE; U.s. Patent No. 5,585,416, issued December 10, 1996, entitled APPARATUS AND METHOD FOR STEP-CHARGING BATTERIES TO OPTIMIZE CHARGE ACCEPTANCE; U.S. Patent No. 5,585,728, issued December 17, 1996, entitled ELECTRONIC BATTERY TESTER WITH AUTOMATIC COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,589,757, issued December 31, 1996, entitled APPARATUS AND METHOD FOR STEP-CHARGING BATTERIES TO OPTIMIZE CHARGE ACCEPTANCE; U.S. Patent No. 5,592,093, issued January 7, 1997, entitled ELECTRONIC BATTERY TESTING DEVICE LOOSE TERMINAL CONNECTION DETECTION VIA A COMPARISON CIRCUIT; U.S. Patent No. 5,598,098, issued January 28, 1997, entitled ELECTRONIC BATTERY TESTER WITH VERY HIGH NOISE IMMUNITY; U.S. Patent No. 5,656,920, issued August 12, 1997, entitled METHOD FOR OPTIMIZING THE CHARGING LEAD-ACID BATTERIES AND AN INTERACTIVE CHARGER; U.S. Patent No. 5,757,192, issued

May 26, 1998, entitled METHOD AND APPARATUS FOR DETECTING A BAD CELL IN A STORAGE BATTERY; U.S. Patent No. 5,821,756, issued October 13, 1998, entitled ELECTRONIC BATTERY TESTER WITH TAILORED COMPENSATION FOR LOW STATE-OF-CHARGE; U.S. Patent No. 5,831,435, issued November 3, 1998, entitled BATTERY TESTER FOR JIS STANDARD; U.S. Patent No. 5,914,605, issued June 22, 1999, entitled ELECTRONIC BATTERY TESTER; U.S. Patent No. 5,945,829, issued August 31, 1999, entitled MIDPOINT BATTERY MONITORING; U.S. Patent No. 6,002,238, issued December 14, 1999, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELLS AND BATTERIES; U.S. Patent No. 6,037,751, issued March 14, 2000, entitled APPARATUS FOR CHARGING BATTERIES; U.S. Patent No. 6,037,777, issued March 14, 2000, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S. Patent No. 6,051,976, issued April 18, 2000, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Patent No. 6,081,098, issued June 27, 2000, entitled METHOD AND APPARATUS FOR CHARGING A BATTERY; U.S. Patent No. 6,091,245, issued July 18, 2000, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Patent No. 6,104,167, issued August 15, 2000, entitled METHOD AND APPARATUS FOR CHARGING A BATTERY; U.S. Patent No. 6,137,269, issued October 24, 2000, entitled METHOD AND APPARATUS FOR ELECTRONICALLY EVALUATING THE INTERNAL TEMPERATURE OF AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Patent No. 6,163,156, issued December 19, 2000,

entitled ELECTRICAL CONNECTION FOR ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,172,483, issued January 9, 2001, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX IMPEDANCE OF CELL AND BATTERIES; U.S. Patent No. 6,172,505, issued January 9, 2001, entitled ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,222,369, issued April 24, 2001, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S. Patent No. 6,225,808, issued May 1, 2001, entitled TEST COUNTER FOR ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,249,124, issued June 19, 2001, entitled ELECTRONIC BATTERY TESTER WITH INTERNAL BATTERY; U.S. Patent No. 6,259,254, issued July 10, 2001, entitled APPARATUS AND METHOD FOR CARRYING OUT DIAGNOSTIC TESTS ON BATTERIES AND FOR RAPIDLY CHARGING BATTERIES; U.S. Patent No. 6,262,563, issued July 17, 2001, entitled METHOD AND APPARATUS FOR MEASURING COMPLEX ADMITTANCE OF CELLS AND BATTERIES; U.S. Patent No. 6,294,896, issued September 25, 2001; entitled METHOD AND APPARATUS FOR MEASURING COMPLEX SELF-IMMITANCE OF A GENERAL ELECTRICAL ELEMENT; U.S. Patent No. 6,294,897, issued September 25, 2001, entitled METHOD AND APPARATUS FOR ELECTRONICALLY EVALUATING THE INTERNAL TEMPERATURE OF AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Patent No. 6,304,087, issued October 16, 2001, entitled APPARATUS FOR CALIBRATING ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,310,481, issued October 30, 2001, entitled ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,313,607,

issued November 6, 2001, entitled METHOD AND APPARATUS FOR EVALUATING STORED CHARGE IN AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Patent No. 6,313,608, issued November 6, 2001, entitled METHOD AND APPARATUS FOR CHARGING A BATTERY; U.S. Patent No. 6,316,914, issued November 13, 2001, entitled TESTING PARALLEL STRINGS OF STORAGE BATTERIES; U.S. Patent No. 6,323,650, issued November 27, 2001, entitled ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,329,793, issued December 11, 2001, entitled METHOD AND APPARATUS FOR CHARGING A BATTERY; U.S. Patent No. 6,331,762, issued December 18, 2001, entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE; U.S. Patent No. 6,332,113, issued December 18, 2001, entitled ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,351,102, issued February 26, 2002, entitled AUTOMOTIVE BATTERY CHARGING SYSTEM TESTER; U.S. Patent No. 6,359,441, issued March 19, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,363,303, issued March 26, 2002, entitled ALTERNATOR DIAGNOSTIC SYSTEM, U.S. Patent No. 6,392,414, issued May 21, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,417,669, issued July 9, 2002, entitled SUPPRESSING INTERFERENCE IN AC MEASUREMENTS OF CELLS, BATTERIES AND OTHER ELECTRICAL ELEMENTS; U.S. Patent No. 6,424,158, issued July 23, 2002, entitled APPARATUS AND METHOD FOR CARRYING OUT DIAGNOSTIC TESTS ON BATTERIES AND FOR RAPIDLY CHARGING BATTERIES; U.S. Patent No. 6,441,585, issued August 17, 2002, entitled APPARATUS AND METHOD FOR TESTING RECHARGEABLE ENERGY STORAGE BATTERIES; U.S.

Patent No. 6,445,158, issued September 3, 2002, entitled VEHICLE ELECTRICAL SYSTEM TESTER WITH ENCODED OUTPUT; U.S. Patent No. 6,456,045, issued September 24, 2002, entitled INTEGRATED CONDUCTANCE AND LOAD TEST BASED ELECTRONIC BATTERY TESTER; U.S. Patent No. 6,466,025, issued October 15, 2002, entitled ALTERNATOR TESTER; U.S. Patent No. 6,466,026, issued October 15, 2002, entitled PROGRAMMABLE CURRENT EXCITER FOR MEASURING AC IMMITTANCE OF CELLS AND BATTERIES; U.S. Serial No. 09/703,270, filed October 31, 2000, entitled ELECTRONIC BATTERY TESTER; U.S. Serial No. 09/780,146,filed February 9, 2001, entitled STORAGE BATTERY WITH INTEGRAL BATTERY TESTER; U.S. Serial No. 09/816,768, filed March 23, 2001, entitled MODULAR BATTERY TESTER; U.S. Serial No. 09/756,638, filed January 8, 2001, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S. Serial No. 09/862,783, filed May 21, 2001, entitled METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S. Serial No. 09/960,117, filed September 20, 2001, entitled IN-VEHICLE BATTERY MONITOR; U.S. Serial No. 09/908,389, filed July 18, 2001, entitled BATTERY CLAMP WITH INTEGRATED CIRCUIT SENSOR; U.S. Serial No. 09/908,278, filed July 18, 2001, entitled BATTERY CLAMP WITH EMBEDDED ENVIRONMENT SENSOR; U.S. Serial No. 09/880,473, filed June 13, 2001; entitled BATTERY TEST MODULE; U.S. Serial No. 09/940,684, filed August 27, 2001, entitled METHOD AND APPARATUS FOR

EVALUATING STORED CHARGE IN AN ELECTROCHEMICAL CELL OR BATTERY; U.S. Serial No. 60/330,441, filed October 17, 2001, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Serial No. 60/348,479, filed October 29, 2001, entitled CONCEPT FOR TESTING HIGH POWER VRLA BATTERIES; U.S. Serial No. 10/046,659, filed October 29, 2001, entitled ENERGY MANAGEMENT SYSTEM FOR AUTOMOTIVE VEHICLE; U.S. Serial No. 09/993,468, filed November 14, 2001, entitled KELVIN CONNECTOR FOR A BATTERY POST; U.S. Serial No. 09/992,350, filed November 26, 2001, entitled ELECTRONIC BATTERY TESTER, U.S. Serial No. 60/341,902, filed December 19, 2001, entitled BATTERY TESTER MODULE; U.S. Serial No. 10/042,451, filed January 8, 2002, entitled BATTERY CHARGE CONTROL DEVICE, U.S. Serial No. 10/073,378, filed February 8, 2002, entitled METHOD AND APPARATUS USING A CIRCUIT MODEL TO EVALUATE CELL/BATTERY PARAMETERS; U.S. Serial No. 10/093,853, filed March 7, 2002, entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION; U.S. Serial No. 60/364,656, filed March 14, 2002, entitled ELECTRONIC BATTERY TESTER WITH LOW TEMPERATURE RATING DETERMINATION; U.S. Serial No. 10/098,741, filed March 14, 2002, entitled METHOD AND APPARATUS FOR AUDITING A BATTERY TEST; U.S. Serial No. 10/101,543, filed March 19, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Serial No. 10/112,114, filed March 28, 2002; U.S. Serial No. 10/109,734, filed March 28, 2002; U.S. Serial No. 10/112,105, filed March 28, 2002, entitled CHARGE CONTROL SYSTEM FOR A VEHICLE BATTERY;

U.S. Serial No. 10/112,998, filed March 29, 2002, entitled BATTERY TESTER WITH BATTERY REPLACEMENT OUTPUT; U.S. Serial No. 10/119,297, filed April 9, 2002, entitled METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S. Serial No. 10/128,790, filed April 22, 2002, entitled METHOD OF DISTRIBUTING JUMP-START BOOSTER PACKS; U.S. Serial No. 60/379,281, filed May 8, 2002, entitled METHOD FOR DETERMINING BATTERY STATE OF CHARGE; U.S. Serial No. 10/143,307, filed May 10, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Serial No. 60/387,046, filed June 7, 2002, entitled METHOD AND APPARATUS FOR INCREASING THE LIFE OF A STORAGE BATTERY; U.S. Serial No. 10/177,635, filed June 21, 2002, entitled BATTERY CHARGER WITH BOOSTER PACK; U.S. Serial No. 10/207,495, filed July 29, 2002, entitled KELVIN CLAMP FOR ELECTRICALLY COUPLING TO A BATTERY CONTACT; U.S. Serial No. 10/200,041, filed July 19, 2002, entitled AUTOMOTIVE VEHICLE ELECTRICAL SYSTEM DIAGNOSTIC DEVICE; U.S. Serial No. 10/217,913, filed August 13, 2002, entitled, BATTERY TEST MODULE; U.S. Serial No. 60/408,542, filed September 5, 2002, entitled BATTERY TEST OUTPUTS ADJUSTED BASED UPON TEMPERATURE; U.S. Serial No. 10/246,439, filed September 18, 2002, entitled BATTERY TESTER UPGRADE USING SOFTWARE KEY; U.S. Serial No. 60/415,399, filed October 2, 2002, entitled QUERY BASED ELECTRONIC BATTERY TESTER; and U.S. Serial No. 10/263,473, filed October 2, 2002, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST

OUTPUT; U.S. Serial No. 60/415,796, filed October 3, 2002, entitled QUERY BASED ELECTRONIC BATTERY TESTER; U.S. Serial No. 10/271,342, filed October 15, 2002, entitled IN-VEHICLE BATTERY MONITOR; U.S. Serial No. 10/270,777, filed October 15, 2002, entitled PROGRAMMABLE CURRENT EXCITER FOR MEASURING AC IMMITTANCE OF CELLS AND BATTERIES; U.S. Serial No. 10/310,515, filed December 5, 2002, entitled BATTERY TEST MODULE; U.S. Serial No. 10/310,490, filed December 5, 2002, entitled ELECTRONIC BATTERY TESTER; U.S. Serial No. 10/310,385, filed December 5, 2002, entitled BATTERY TEST MODULE, U.S. Serial No. 60/437,255, filed December 31, 2002, entitled REMAINING TIME PREDICTIONS, U.S. Serial No. 60/437,224, filed December 31, 2002, entitled DISCHARGE VOLTAGE PREDICTIONS, U.S. Serial No. 10/349,053, filed January 22, 2003, entitled APPARATUS AND METHOD FOR PROTECTING A BATTERY FROM OVERDISCHARGE, U.S. Serial No. 10/388,855, filed March 14, 2003, entitled ELECTRONIC BATTERY TESTER WITH BATTERY FAILURE TEMPERATURE DETERMINATION, U.S. Serial No. 10/396,550, filed March 25, 2003, entitled ELECTRONIC BATTERY TESTER, U.S. Serial No. 60/467,872, filed May 5, 2003, entitled METHOD FOR DETERMINING BATTERY STATE OF CHARGE, U.S. Serial No. 60/477,082, filed June 9, 2003, entitled ALTERNATOR TESTER, U.S. Serial No. 10/460,749, filed June 12, 2003, entitled MODULAR BATTERY TESTER FOR SCAN TOOL, U.S. Serial No. 10/462,323, filed June 16, 2003, entitled ELECTRONIC BATTERY TESTER HAVING A USER INTERFACE TO CONFIGURE A

PRINTER, U.S. Serial No. 10/601,608, filed June 23, 2003, entitled CABLE FOR ELECTRONIC BATTERY TESTER, U.S. Serial No. 10/601,432, filed June 23, 2003, entitled BATTERY TESTER CABLE WITH MEMORY; U.S. Serial No. 60/490,153, filed July 25, 2003, entitled SHUNT CONNECTION TO A PCB FOR AN ENERGY MANAGEMENT SYSTEM EMPLOYED IN AN AUTOMOTIVE VEHICLE, which are incorporated herein in their entirety.

There is an ongoing need to measure parameters of electrical systems of vehicles and heavy equipment. Such measurements can be used to diagnose operation, failure or impending failure of components or subsystems of electrical systems. For example, in electrical systems used in vehicles, measurement of electrical parameters of such systems can be used to diagnose operation of system or indicate that maintenance is required before ultimate failure.

One particular measurement is the resistance of cabling used in large equipment such as heavy trucks. For example, one such cable or set of cables connects the battery of vehicle to the starter motor. The starter motor has a relatively large current draw and even a relatively small cable resistance can have a significant impact on operation of the starter motor.

Because the cable resistance is relatively small it typically cannot be measured using a standard ohm meter or other techniques which are

normally used to measure resistance. One technique which has been used to measure the cable resistance is to run a very large current through the cable and measure the voltage drop. However, this is cumbersome and requires components capable of handling the large current.

SUMMARY OF THE INVENTION

An apparatus for measuring electrical parameters for an electrical system includes measurement circuitry which is configured to measure a first parameter of the electrical system between a first connection to the electrical system and a second connection to the electrical system. The measurement circuitry is further configured to measure a second parameter of the electrical system between a third connection to the electrical system and the second connection to the electrical system. A processor determines a third electrical parameter of the electrical system as a function of the first parameter and the second parameter. A method can also be employed.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a simplified diagram of an electrical system of a vehicle.

Figure 2 is a diagram showing test equipment for determining the resistance of cables of the electrical system shown in Figure 1.

Figure 3 shows another example embodiment of test equipment for determining cable resistance.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a diagram of an electrical system 10 of large equipment 12 such as a heavy truck. Electrical system 10 includes a battery 20, a high current load 22 and cables 24 and 26. Cables 24 and 26 have resistances R_1 and R_2, respectively and connect load 22 to battery 20. Figure 1 also shows connection points C, D and C', D'. Connections C and D are cross load 22 and connections C' and D' are cross battery 20.

As discussed in the Background section, the resistances R_1 and R_2 of cables 24 and 26 can have a significant impact on the amount of power which can be delivered to load 22. Even if the resistance values are relatively small, because a relatively large current passes through cables 24 and 26, the resultant voltage drop can significantly reduce the voltage at points C and D and therefore the amount of power (or voltage) which can be delivered to load 22. In industrial equipment, it is often desirable to measure the resistance R_1 and R_2 of cables 24 and 26, respectively, in order to identify a cable with a resistance which is too high. One technique which has been used to measure the resistance of the cables is to pass a large current through the cable and measure the resulting voltage drop across the cable. However, this is a cumbersome test and requires electrical test equipment which is capable of handling the large current draw. The present invention provides an

apparatus and technique for measuring the resistance of a cable in a configurations similar to that shown in Figure 1.

Figure 2 is a simplified block diagram of one example embodiment of electrical test equipment 50 for measuring electrical parameters of the electrical system 10 shown in Figure 1. Test equipment 50 includes measurement circuitry 52, microprocessor 54, memory 56 and output 58. Measurement circuitry 52 is configured to couple to electrical system 10 of Figure 1 through electrical connections 60 and 62. Measurements obtained by measurement circuitry 52 are used by microprocessor 54 in accordance with program instructions contained in memory 56. Based upon the measurements, an output is provided through output 58, for example, to a user or to other equipment. Connectors 60 and 62 are configured to couple to points C, D and C', D' in order to measure parameters of system 10. Any number of connectors may be used and the invention is not limited to the two illustrated in Figure 2.

In one aspect of the present invention, test equipment 50 measures a parameter P(C,D') between points C and D' and a parameter P(C',D') between points C' and D'. These measurements are used to determine the resistance of R_1 in accordance with the formula:

$$R_1 = F[P(C,D'), P(C',D')] \qquad \text{EQ. 1}$$

Further, a third measurement can be taken to obtain a parameter P(C',D) between points C' and D in Figure 1. With this additional parameter, the resistance of R_2 can be determined as:

$$R_2 = F\{P(C',D),\ P(C',D')\} \qquad \text{EQ. 2}$$

Microprocessor 54 can determine the actual values of R_1 and R_2, or can make some other determination related to R_1 and R_2, for example a pass/fail determination, a relative determination, a gradient based determination, etc. Microprocessor 54 provides an output through output 58 based upon the determination related to R_1 and R_2. The output can be a visual output, audible output, or the like, to an operator. In another example, the output is suitable for receipt by other circuitry.

Figure 3 is a simplified diagram showing another example embodiment of circuitry in accordance with the present invention. In Figure 3, test equipment 100 includes a microprocessor 54, memory 56 and output 58, similar to the configuration discussed with respect to Figure 2. Additionally, measurement circuitry 102 is provided for coupling to the C,D and C',D' connections shown in Figure 1. More specifically, Kelvin connections 104 and 106 are provided and are identified as A, B, C and D with connections 104B, 106A, 104A and 106B, respectively. Kelvin connection 104 is configured to couple to location C shown in Figure 1. Kelvin connection 106 is configured to couple to location D shown in Figure

1. An additional pair of connections 108 and 110 are configured to couple to locations C' and D' shown in Figure 1. A forcing function 120 couples to connections 104B and 106A (A and B) and is configured to apply a time varying signal therebetween. The signal can be any type of time varying signal including a periodic signal and may have any type of waveform at a desired frequency or multiple frequencies. Further, in some embodiments, measurements are taken using different forcing functions at differing frequencies or waveforms. The forcing function can be an active signal which is injected through the A/B connection, or can be a passive signal in which a signal is drawn from points A/B through selective application of a resistance, etc.

An amplifier 122 couples to connections 104A and 106B (C and D) and provides an output to an analog to digital converter 124. Connections 108 and 110 (C' and D') couple to an amplifier 126 which provides an output to analog to digital converter 124. Note that this configuration is for explanation only and other configurations can be implemented in accordance with the present invention including different amplifier configurations, different analog to digital converter configurations, etc. Further, the forcing function 120 can be an active forcing function in which a signal is actively applied or can be a passive forcing function in which a signal is

applied passively through a resistance or the like which is selectively applied to draw current from battery 20 shown in Figure 1. The circuitry can be implemented in analog or digital circuitry, or their combination. Circuitry in accordance with techniques set forth in the Background section can be implemented, or other measurement techniques can be used.

Using the configuration set forth in Figure 3, Kelvin connections 104 and 106 can be applied to points C and D identified in Figure 1. Additional connections 108 and 110 can be applied to points C' and D' shown in Figure 1. Using this configuration, the parameters measured in accordance with Figures 1 and 2 can be dynamic parameters which are functions of the applied forcing function 120. In another example embodiment, a single pair of Kelvin connections is used in which the connections are moved between various positions C, D, C' and D' shown in Figure 1 and the resistance R_1 and R_2 of the cables 24 and 26 are determined.

Using the circuitry set forth in Figure 3, conductance values between the various connections shown in Figure 1 can be obtained. Using these conductance values, the resistances R_1 and R_2 can be determined using the following equations:

$$R_1 = (K_1/G_{CD'}) - (K_2/G_{C'D'}) \qquad \text{EQ. 3}$$

$$R_2 = (K_3/G_{C'D}) - (K_4/G_{C'D'}) \qquad \text{EQ. 4}$$

Where $G_{CD'}$ is the conductance measured between points C and D', $G_{C'D'}$ is the conductance measured between points C' and D' and $G_{C'D}$ is the conductance measured between points C' and D. The values K_1, K_2, K_3 and K_4 are constants and can be, in some examples, the same value, for example unity. The conductance values can be either direct conductance values or can be conductance values converted to a cold cranking amps (CCA) scale. When CCA values are measured, he values of R_1 and R_2 can be determined using the formula:

$$R_1 = (3.125/CCA\_CD')-(3.125/CCA\_C'D') \quad \text{EQ. 5}$$

$$R_2 = (3.125/CCA\_C'D)-(3.125/CCA\_C'D') \quad \text{EQ. 6}$$

The value of 3.125 can be adjusted based upon the particular CCA scale employed.

The load 22 can be any type of load including loads which draw high current levels, for example, a starter motor, a magnetic switch, a ground connection, wiring harness, a terminal which may be susceptible to corrosion, a connection through a bolt which may have inappropriate torque or otherwise provide a poor connection, trailer wiring, etc. In one example output, a particular voltage drop is provided for a particular current draw through the cabling. For example, the output can comprise an indication that there is a 0.5 volt drop through the cable under a 500 amp current. Such a parameter can also be used, for example, in a pass/fail test, i.e., if the voltage drop is more than a particular threshold at a given current level, a failure

indication can be provided as an output. In one embodiment, the measured parameters comprise dynamic conductance. However, any dynamic parameter can be used in accordance with the present invention including dynamic resistance, reactance, impedance, conductance, susceptance, and/or admittance, including any combination of these parameters.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. The measurements can be taken using multiple connections to the electrical system or by moving a single pair of connections to various positions on the electrical system. An output can be provided to instruct the operator where to place the connections.